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Thomas W. Showalter and Robert J. Miller
Ames Research Center
Moffett Field, California



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G-SEAT SYSTEM STEP INPUT AND SINUSOIDAL RESPONSE CHARACTERISTICS

Thomas W. Showalter* and Robert J. Miller

Ames Research Center

SUMMARY

The step input and the sinusoidal response characteristics of a pneumatically driven computer controlled G-seat system were determined and described in this study. Step inputs of varying amplitudes and large amplitude sinusoids of a series of frequencies were input to the system. The response data show that this G-seat system can be modeled as a first order system with an 0.08 sec time lag and a 0.53 sec time constant. The system is essentially a low-frequency system and its use as an aircraft simulator subsystem should be confined to cueing low frequency (i.e., ≤ 4.5 rad/sec) aircraft accelerations.

INTRODUCTION

The present study is an effort designed to describe the dimensional, phase, amplitude ratio, and step response characteristics of the G seat, pictured in figure 1. The G seat, which consists of two groupings of pneumatic cells, one in the seat pan and the other in the back, is a new type of aircraft simulator subsystem. The Gseat attempts to induce the illusion of acceleration within a pilot by creating those somatic stimuli, such as skin pressure changes and body position cues, that are thought to be closely associated with a pilot's perception of acceleration. Operationally, as the simulator pilot guides his vehicle through a variety of maneuvers, G-seat back and pan contours change shape in accordance with guidelines in a computer software program. Such contour changes, hopefully, stimulate the pilot's perceptual system to create the illusion of acceleration.

It is hoped that the data presented in this paper will enable researchers to better describe the stimuli presented to the pilot by this cueing system and to better anticipate



Figure 1.— G-seat photograph.

*USAF Laboratory Associate.

how G-seat stimuli might interact with other stimuli (e.g., visual stimuli) that are presented in the dynamic flight simulator environment.

METHODS

System Description

Figure 2 is a block diagram showing the relationships of major components of the system in this study. Overall simulation computation is done in a digital computer and converted to analog form to be transmitted to the analog computer where biasing and scaling are done. At the valve pack, transducers convert the analog voltage signals to pressures, which actuate movable cells in the seat. Position and pressure transducer outputs follow a reverse path. In the present study, the digital computer is not used and drive signals originate at either the analog machine or a frequency response analyzer.

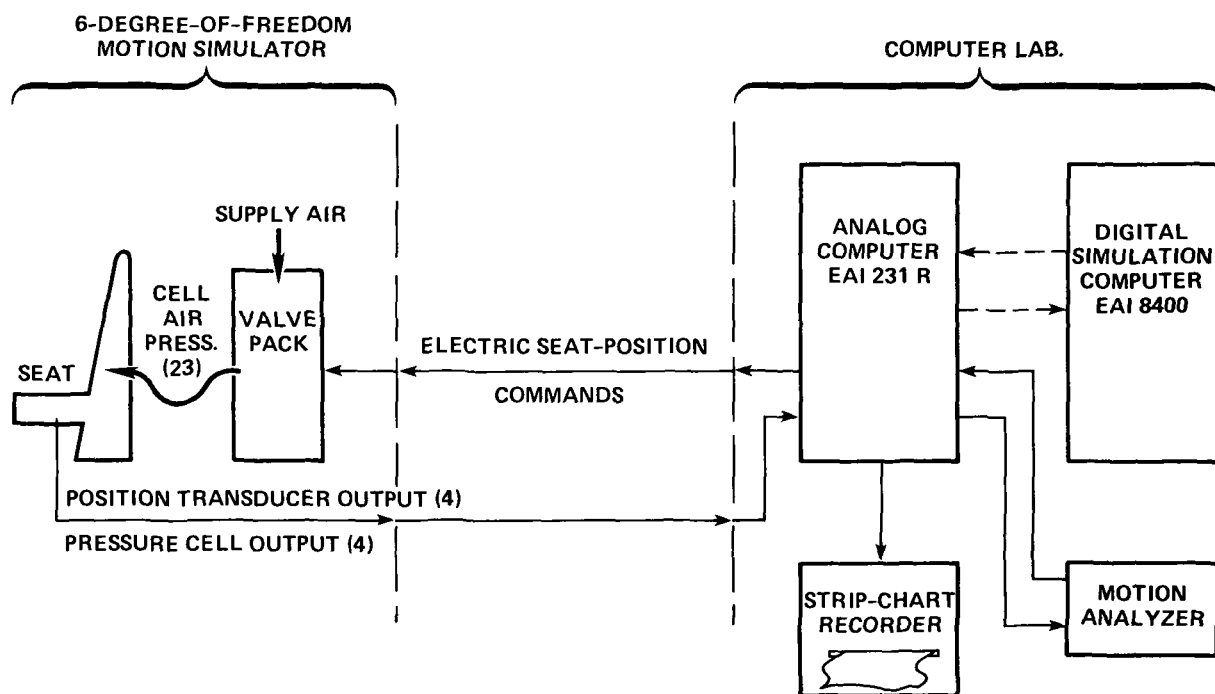


Figure 2.— G-seat system diagram.

G Seat

The G seat is pictured in figure 1 and diagrammed in detail in figure 3. The surface is formed by 23 independently controlled cells, 14 in the seat and 9 in the back, which are shown in a numbered diagram in figure 4. Each cell consists of a metal bellows (or two, in the case of the lower six back cells) mounted in a supporting pan and topped by a rectangular plate. Plates are covered

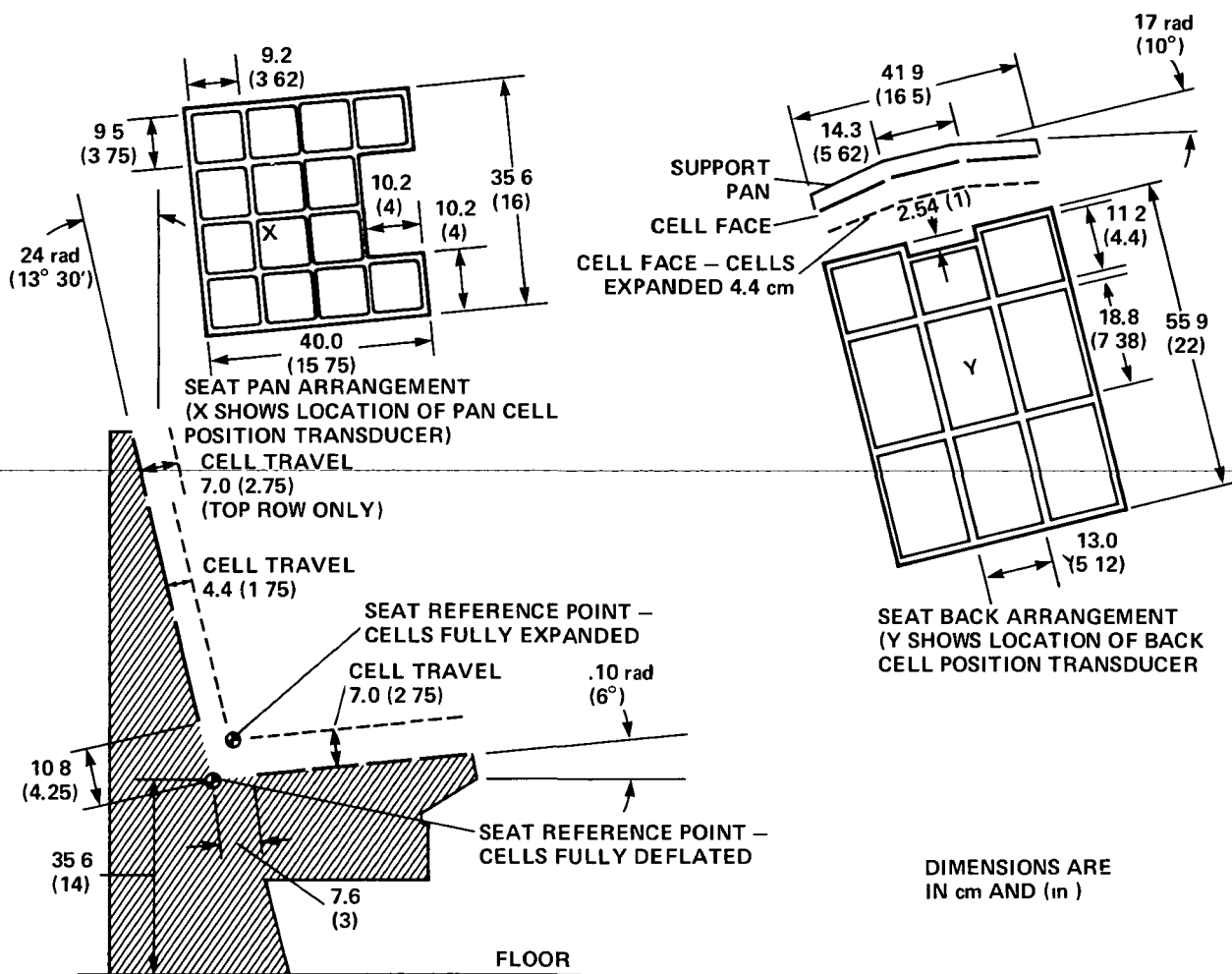


Figure 3.— G-seat dimensions

with a pad 1.27 cm (0.5 in.) thick, and a removable fabric cover. Each seat cell has a pressure sensitivity of 17 cm/atm (0.46 in./psi). As a result, each unloaded seat cell reaches its 7 cm (2.75 in.) maximum extension with 0.4 atmosphere (6 psi) pressure. The lower six back cells have two bellows each and a maximum extension of 4.5 cm (1.75 in.) at 0.53 atm (7.7 psi). Cell top plates tilt freely through small angles, giving the impression to the occupant that the seat surfaces are continuous and conforming, even though adjacent cells may be differentially extended.

The bellows and pan assemblies are mounted in a standard U.S. Air Force transport-category aircraft seat with arm rests removed, so the resulting seat conforms to standard design practice, with the exception of allowable seat

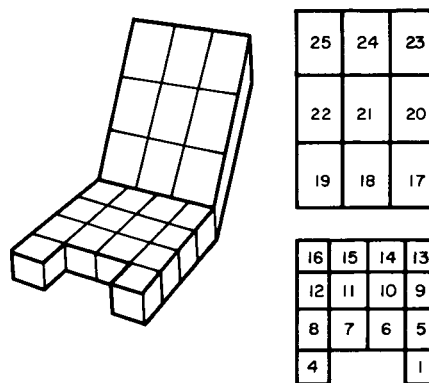


Figure 4.— G-seat cell diagram.

adjustments. As installed in the Ames six-degree-of-freedom motion simulator, only a very limited fore-and-aft adjustment is available.

A seat belt is installed with the capability of tightening or extending in conjunction with seat-cell motion, although this capability is not investigated in this study. A shoulder harness is also installed, modified for safety reasons so that the inertia reel could not inadvertently lock as the cells are pressurized.

Cell no. 11 in the seat and cell no. 21 in the back were instrumented to measure extension and pressure. The position transducers are of the resistive type, connected to cell plates with light cable. Pressure transducers are integrated circuit devices. Note from figure 3 that the seat-cell position transducer connects at one corner of the plate. It was not possible to work inside the bellows to obtain true extension, so transducer reading could be sensitive to tilt. However, due to the use of a clamping device (to be discussed subsequently) tilt errors were minimized and sensor readings revealed accurate cell extensions.

Valve Pack

The valve pack consists of a series of ITT "Conoflo" Model T-25 electropneumatic valves. These are two-stage devices with a fluidic transducer, followed by a diaphragm-operated booster stage, producing an output pressure range of 0 to 1.02 atm (0–15 psi) from a source pressure of 1.70 atm (25 psi). The valves are a type generally used in low-frequency ($\ll 1$ Hz) process-control applications, and are not well-characterized by the manufacturer for higher speeds. Also installed at the valve pack are the potentiometers used to adjust cell calibration and compensate for spring rate variations. The valve pack is connected to the seat with 0.62 cm (0.25 in.) inside diameter flexible tubing 11 m (36 ft) long. Note that each connecting tube has a volume approximately equal to that of an extended bellows. It is unfortunate that shorter connecting lines could not be used, as long lines would be expected to worsen the bellows' response characteristics.

Frequency Response Analyzer

The frequency response analyzer is a compact digital system that combines a function generator, that may be connected to the input of a system under test, with circuitry in order to compare the output of that system with its input and to display the relative amplitude and phase. The display has a log amplitude/phase mode that yields a Bode plot directly. The frequency range of the instrument is 0.1 mHz to 10 kHz. Output power is limited, however, so the analog computer was used to buffer the output.

Procedures

The response of the G seat was measured with two types of input signal, a step input and sine waves of constant amplitude and varying frequency.

Back and seat cells no. 11 and no. 21 were tested independently. The tests were done under a no-load condition and with a 79.5 kg (165 lb) occupant seated normally. Precautions were taken to

assure that the sensitivity to tilt of the instrument seat cell did not perturb the data. For the unloaded test, the fabric cover was removed and the instrumented cell plate clamped to two adjoining cell plates to constrain all three to move simultaneously and in parallel. The same signal was applied to all cells in the group. For the loaded tests, the same signal was again applied to all cells. It was found that if the occupant was centered and sat still, the cells were adequately constrained to give repeatable results.

Step Response Tests

Step response was obtained by manually switching the input to the seat between two signal levels set by attenuators at the analog computer and recording the seat response on an 8-channel strip chart recorder. Input signal, cell position, and cell pressure were recorded initially, but cell pressure followed cell position so closely as to be redundant and was omitted. All combination of steps between 10%, 50%, and 90% of full extension across both load and no-load conditions were recorded. At either loading condition, signal levels were set empirically to bias the cells at 50% travel and remain within the 10% to 90% limits. A digital voltmeter on the analog computer was switched to the position transducer to set and monitor cell travels.

Sine-Wave Response

For sine-wave tests, the function generator output of the frequency response analyzer instrument was amplified in the analog computer and applied to the group of cells under test (i.e., seat pan, seat back). The position transducer output was returned to the instrument for comparison with the system input. At the function generator, bias and sine-wave amplitude were independently controlled to set cell excursions at approximately 10% to 90% of full travel, as in step response tests. These levels were set at 0.1 Hz, a frequency which allowed cell position to be followed readily on the analog computer's digital voltmeter, and yielded a response within 0.2 dB of that of the lowest frequencies used in the tests. Two loading conditions were used, no load and a seated occupant of 79.5 kg (165 lb). It was found that only the bias needed to be changed with weight; with constant sine-wave input amplitude the response varied less than 2% from no-load to full-load conditions. Eighteen input frequencies were used, from 0.13 rad/sec (0.02 Hz) to 31.4 rad/sec (5 Hz) in an approximate geometrical progression of ratio 1.4. The amplitude ratios are shown in decibels. The combined plots are the control engineer's familiar Bode Plots.

RESULTS AND DISCUSSION

The step response data shown in table 1 depicts the time lag and time constant data for a variety of test conditions for cell no. 11. Cell no. 11 is equivalent in construction and operation to that of all the other G-seat cells and is equivalent in response characteristics to cell no. 21. As a result, the table 1 data is considered representative of the whole G-seat system step response characteristics.

Figure 5 reveals the shape of the cell no. 11 response to a cell inflation step input, which started with the cell top positioned at the 10% travel point (i.e., 0% equals full deflation, 100%

TABLE 1.— G-SEAT PAN CELL NO 11 STEP INPUT
RESPONSE DATA

Start position, %	Stop position, %	Deflate (D) inflate (I)	Load ^a factor	Time lag, ms (A) ^b	Time constant, sec (B) ^b
90 ^c	10	D	Load	75	0 61
10	90	I	Load	70	57
50	10	D	Load	85	52
50	90	I	Load	100	54
90	10	D	No load	75	54
10	90	I	No load	80	52
50	10	D	No load	90	46
50	90	I	No load	90	46

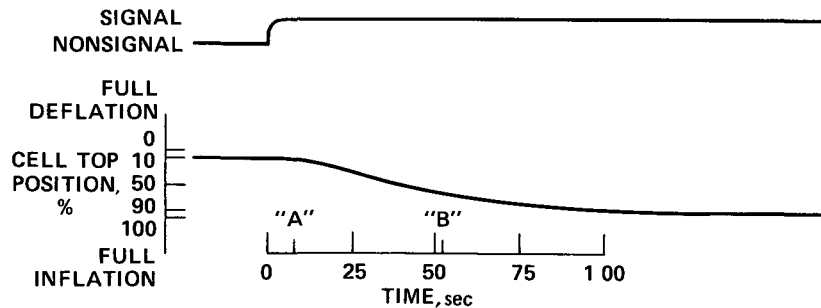
Average 83 13 0 53

Standard deviation 9 98 0 0509

^aLoad equaled a seated 75 kg (165 lb) man

^bFor a graphic description of "A" and "B" see the example in figure 5

^cThe term "X" % means the point at which the cell top had expanded to "X"/100 of the total travel limits, with 0% being total cell deflation and 100% being total cell inflation



"A" TIME LAG (i e. TIME BETWEEN SIGNAL AND CELL RESPONSE)

"B" TIME CONSTANT (i e TIME UNTIL 63 2% OF THE INTENDED TRAVEL HAS OCCURRED)

THE "LOAD" WAS A 75 kg (165 lb) SEATED MAN

Figure 5.— G-seat pan cell no. 11 step input response data under loaded conditions.

equals full inflation) and ended with the cell top at the 90% travel point. Under all test conditions, cell no. 11 approached its commanded position with no tendency to overshoot, indicating either an overdamped second-order system or first-order system.

Given the low variance of the time lag and the time constant measurements and the uniform shape of the step response curves across all test conditions, it is apparent that the various test conditions did not alter this G-seat system's step response characteristics. The system exhibits a noteworthy time lag (i.e., 0.08 sec) before responding and thereafter inflates (deflates) at a slow rate (i.e., time constant = 0.53 sec) regardless of the presence or absence of a moderate load factor (i.e., a 79 kg (165 lb) seated man).

The effects of a series of sinusoidal inputs upon G-seat cell no. 11 are depicted in figure 6, a Bode Plot diagramming the phase and amplitude of ratio characteristics of that cell. Cell no. 11 was shown to have equivalent phase and amplitude ratio characteristics in either the loaded (i.e., 65 kg man) or unloaded conditions. As a result, the figure 6 data is representative of the G-seat system response characteristics in either the loaded or unloaded conditions. The phase and amplitude data, when viewed together with the step response data, suggest that the system can be modeled as a first-order system with an 0.08 sec time lag as follows:

$$\frac{\text{output (position)}}{\text{command (position)}} = (e^{-0.083 \text{ s}}) \frac{1}{0.53 \text{ s} + 1}$$

Shown in figure 6 is a comparison of the theoretical system defined above with the actual data. The correspondence for both phase and amplitude data is very close, which strongly suggests that the theoretical model is appropriate.

The time lag, resulting in large part from the unavoidably long lines and the two-stage valves, has an increasingly adverse effect upon system phase performance as the system input frequency

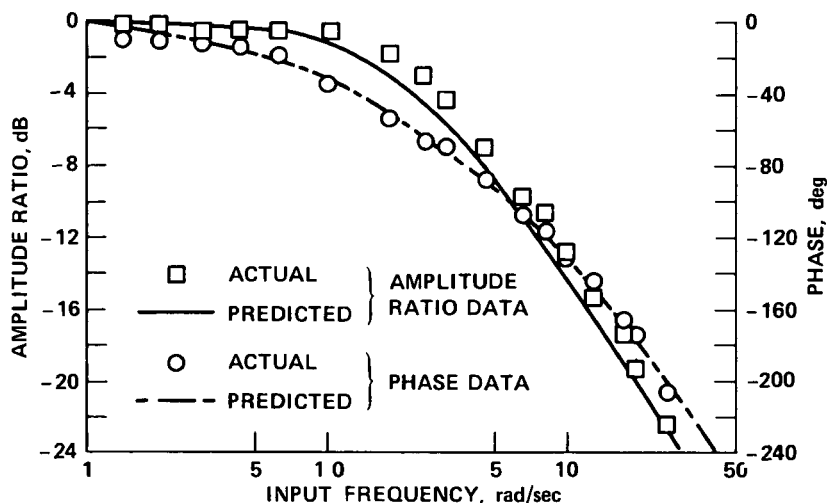


Figure 6.— G-seat frequency response characteristics.

increases. Such phase characteristics indicate that the system can present accurate and timely information (i.e., less than 90° phase lag) only at lower frequencies (i.e., ≤ 4.5 rad/sec). Presenting higher frequency information via this system would create cues that are so out of phase with the aircraft's situation as to be irrelevant or misleading

The amplitude ratio characteristics, which also decay rapidly at higher input frequencies, would probably have a less significant impact on the information value of the G-seat cue. The human somatic sensing system, especially the tactile system, is extremely sensitive and, therefore, only small cell top position changes are needed in order to stimulate the somatic senses. As a result, if high-frequency cueing is required, it is suggested that the system's phase characteristics be improved before extensive efforts are made to improve the system's amplitude ratio characteristics.

Compensating this system so as to improve its high frequency phase characteristics has been avoided to date. In operation, the G-seat software is constantly converting aircraft acceleration data into G-seat cell position computations. To construct a lead network would require the computation of the derivative of aircraft acceleration (i.e., calculate the third derivative of aircraft position). Such computational procedures have not been attempted as yet, but would warrant investigation.

CONCLUSIONS

The response data show that this G-seat system, a pneumatically driven computer controlled system, can be modeled as a first-order system with a 0.08 sec time lag and a 0.53 time constant. The system, as shown by the data, is essentially a low-frequency system and its use as a simulator subsystem should be confined to cueing low-frequency aircraft accelerations

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